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(54) Title: IMPROVEMENTS RELATING TO CANCER THERAPY

(57) Abstract

The system of the invention comprises: (i) a viral vector comprising a nucleotide sequence encoding a nitroreductase, which nitroreductase is capable of converting a prodrug into a cytotoxic drug; and (ii) a prodrug capable of being converted into a cytotoxic drug by the nitroreductase encoded by the vector.

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- 1 -

IMPROVEMENTS RELATING TO CANCER THERAPY

The present invention relates to viral mediated gene therapy and its use in the treatment of tumours.

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A therapeutic approach termed "virus-directed enzyme prodrug therapy" (VDEPT) has been proposed as a method for treating tumour cells in patients using prodrugs. Tumour cells are targeted with a viral vector carrying a gene encoding an enzyme capable of activating a prodrug. The gene may be transcriptionally regulated by tissue specific promoter or enhancer sequences. The viral vector enters tumour cells and expresses the enzyme, in order that a prodrug is converted to an active drug only in the vicinity of the tumour cells (Huber et al, Proc. Natl. Acad. Sci. USA (1991) 88, 8039).

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Although the VDEPT system enhances the concentrations of anti-tumour agent which may be delivered to the site of a tumour, there is still a need to enhance the specificity and efficiency of drug delivery.

The present invention addresses such problems by the use of a VDEPT viral vector which encodes for a nitroreductase.

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The present invention therefore provides a system comprising:

(i) a viral vector comprising a nucleotide sequence encoding a nitroreductase, which nitroreductase is capable of converting a prodrug into a cytotoxic drug; and

(ii) a prodrug capable of being converted into an active drug by the nitroreductase encoded by the vector.

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The invention also provides a kit which comprises a vector defined herein together with a prodrug as defined herein.

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In another aspect, the invention provides a system as defined herein or a kit as defined herein for use in a method of treatment of the human or animal body, and in particular a method

- 2 -

of treatment of tumours.

In a further aspect, the invention provides a method of treatment of tumours which comprises administering to an individual with a tumour (i) an effective amount of a vector as defined herein, and (ii) an effective amount of a prodrug capable of being converted to an active drug by the nitroreductase encoded by the vector.

10 In a further embodiment, the invention provides a method of ablating normal tissue which comprises administering to a human or animal body an effective amount of a vector as defined herein and an effective amount of a prodrug capable of being converted to an active drug by a nitroreductase encoded by the vector.

15 In a further embodiment the invention provides a product containing a viral vector as defined herein and a prodrug as defined herein as a combined preparation for simultaneous, separate or sequential use in the treatment of tumours or the 20 ablation of tissue.

The viral vector may be any suitable vector available for targeting tumour cells, such as, for example, retroviral, adenoviral or virosomal vectors. Huber et al Proc., Natl. Acad. 25 Sci. USA (1991), 88, 8039, report the use of amphotrophic retroviruses for the transformation of hepatoma, breast, colon or skin cells. Culver et al (Science (1992) 256; 1550-1552) also describe the use of retroviral vectors in VDEPT, as do Ram et al (Cancer Research (1993) 53; 83-88). Englehardt et al (Nature Genetics (1993) 4; 27-34) describe the use of adenovirus based 30 vectors in the delivery of the cystic fibrosis transmembrane conductance product (CFTR) into cells.

Accordingly, any suitable RNA or DNA vector including vectors of 35 the type mentioned above may be used in the preparation of a vector according to the invention. Those of skill in the art will be able to prepare vectors which will be modified by genetic

- 3 -

engineering techniques known per se, such as those described by Sambrook et al (Molecular Cloning: A Laboratory Manual, 1989).

5 Preferably, the viral vector of the invention comprises a promoter operably linked to the gene encoding the nitroreductase. "Operably linked" refers to a juxtaposition wherein the promoter and the enzyme-coding sequence are in a relationship permitting the coding sequence to be expressed under the control of the promoter. Thus, there may be elements such as 5' non-coding sequence between the promoter and coding sequence which is not native to either the promoter or the coding sequence. Such sequences can be included in the vector if they do not impair the correct control of the coding sequence by the promoter. Suitable 10 promoters include tissue and tumour specific promoters, such as, for example, the promoter for milk protein, the CEA gene promoter or the CA-125 gene promoter. Promoters for milk protein include the LH $\beta$  promoter, preferably from sheep, the  $\beta$ -lactoglobulin (BLG) promoter, the  $\alpha$ -lactalbumin promoter and the whey acidic 15 protein promoter.

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Although it is preferred to include in the vector a native mammalian or human promoter sequence, modified promoter sequences which are capable of selectively hybridizing to the mammalian or 25 human sequence may be included in the vector. A promoter sequence capable of selectively hybridizing to the human promoter sequence will be generally at least 70%, preferably at least 80 or 90% and more preferably at least 95% homologous to the promoter region or fragment thereof over a region of at least 20, 30 preferably at least 30, for instance 40, 60 or 100 or more contiguous nucleotides.

In general, those of skill in the art will appreciate that some 35 regions of promoters will need to be retained to ensure tissue specificity of expression from the vector whereas other regions of the promoter may be modified or deleted without significant loss of specificity.

- 4 -

For use of the vectors in therapy, the vectors will usually be packaged into viral particles and the particles delivered to the site of the tumour, as described in for example Ram et al (ibid). The particles may be delivered to the tumour by any suitable means at the disposal of the physician. For example, parenterally. Preferably, the viral particles will be capable of selectively infecting the tumour cells. By "selectively infecting" it is meant that the viral particles will primarily infect tumour cells and that the proportion of non-tumour cells infected is such that the damage to non-tumour cells by administration of a prodrug will be acceptably low, given the nature of the disease being treated. Ultimately, this will be determined by the physician.

One suitable route of administration is by injection of the particles in a sterile solution.

The nitroreductase of the system of the invention includes fragments and homologues thereof which retain the nitroreductase activity. A nitroreductase according to the invention is an enzyme capable of reducing a nitro group to the corresponding hydroxylamino group in various compounds.

The gene encoding the nitroreductase preferably comprises the oligonucleotide of the sequence shown in SEQ ID NO: 1, a fragment thereof or oligonucleotide hybridisable thereto. An oligonucleotide capable of hybridising to the oligonucleotide of SEQ ID NO: 1 or fragment thereof will generally be at least 70%, preferably at least 80 or 90% and more preferably at least 95% homologous to the oligonucleotide of SEQ ID NO: 1 or fragment thereof over a region of at least 20, preferably at least 30, for example 40, 60 or 100 or more contiguous nucleotides. The sequence of the oligonucleotide may be varied by deleting at least one nucleotide, inserting at least one nucleotide or substituting at least one nucleotide in the sequence.

The oligonucleotides may be RNA or DNA. The oligonucleotide

- 5 -

fragments typically will be at least 10, for example at least 20, 30, 40, 60 or 100 nucleotides long.

5. The nitroreductase encoded by the vector is preferably bacterial nitroreductase, for example a nitroreductase which is a flavoprotein having a molecular weight in the range 20 to 60 kDa, which requires NADH or NAD(P)H or analogues thereof as a cofactor and which has a  $K_m$  for NADH or NAD(P)H in the range 1 to 100  $\mu$ M such as that described in EP-A-540 263. Typically the 10 nitroreductase is the same as that from E. Coli, Salmonella or Clostridia organisms.

15. Preferably the nitroreductase of the invention is a nitroreductase having the sequence of SEQ ID No: 2, a fragment thereof or homologue thereof.

20. A nitroreductase of SEQ. ID No. 2 in substantially purified form will generally comprise the protein in a preparation in which more than 90%, eg. 95%, 98% or 99% of the protein in the preparation is that of the SEQ. ID No. 2.

25. A homologue of the SEQ. ID No. 2 will be generally at least 70%, preferably at least 80 or 90% and more preferably at least 95% homologous to the protein of SEQ. ID No. 2 over a region of at least 20, preferably at least 30, for instance 40, 60 or 100 or more contiguous amino acids.

30. Generally, fragments of SEQ. ID No. 2 or its homologues will be at least 10, preferably at least 15, for example 20, 25, 30, 40, 50 or 60 amino acids in length. The sequence of the polypeptide may be varied by deleting, inserting or substituting at least one amino acid.

35. The prodrug which will be used in conjunction with the vector of the invention will be a compound which can be converted by the nitroreductase encoded by the vector into a cytotoxic drug. Desirably, the toxicity of the prodrug to the patient being

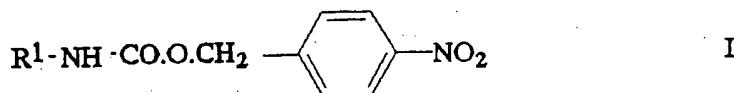
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treated will be at least one order of magnitude less toxic to the patient than the active drug. Preferably, the cytotoxic drug will be several, eg 2, 3, 4 or more orders of magnitude more toxic.

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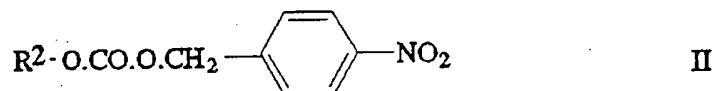
Suitable prodrugs include nitrogen mustard compounds and other compounds such as those described in WO93/08288 or EP-A-540 263. Preferred prodrugs are compounds of the general formula:

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and:

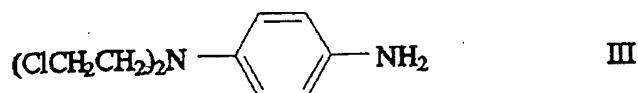


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where  $R^1$  and  $R^2$  are groups such that the compound  $R^1\text{NH}_2$  and  $R^2\text{OH}$  are cytotoxic compounds.

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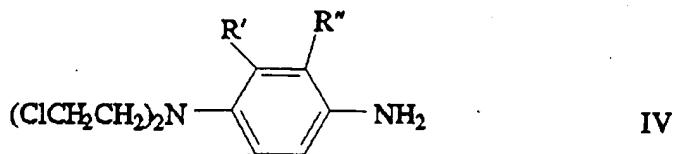
It is preferred that compounds  $R^1\text{NH}_2$  and  $R^2\text{OH}$  are aromatic cytotoxic compounds and the compounds  $R^1\text{NH}_2$  can be any one of the well known nitrogen mustard compounds, for example based on p-phenylene diamine. Thus, the compound  $R^1\text{NH}_2$  can be:



- 7 -

or analogues of this compound with the general structure IV

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where R' and R'' are H, F or CH<sub>3</sub>, and particularly where

10 R' = H and R'' = CH<sub>3</sub>;  
 or R' = CH<sub>3</sub> and R'' = H;  
 or R' = H and R'' = F;  
 or R' = F and R'' = H.

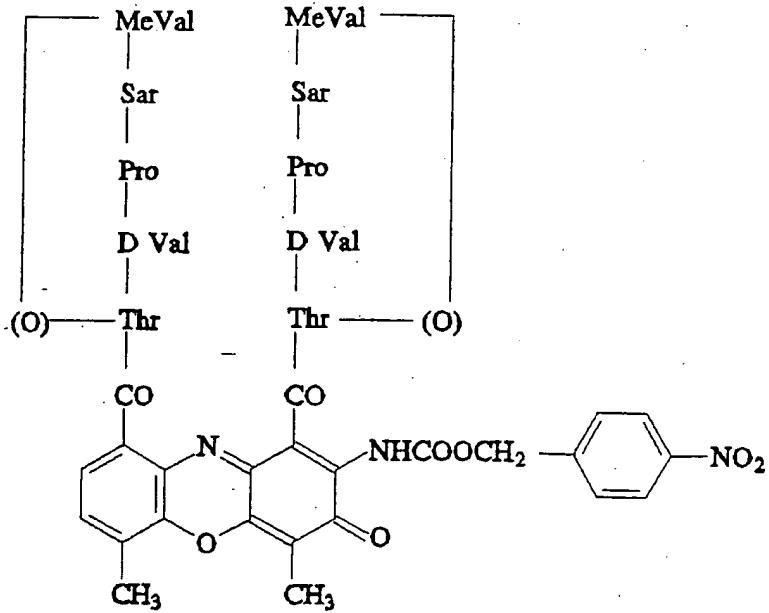
15 Further types of amino cytotoxic compounds that can be used in accordance with the present invention are compounds such as actinomycin D, and mitomycin C. The structure of the pro-drugs derived from actinomycin D and mitomycin C are shown below as V and VII respectively.

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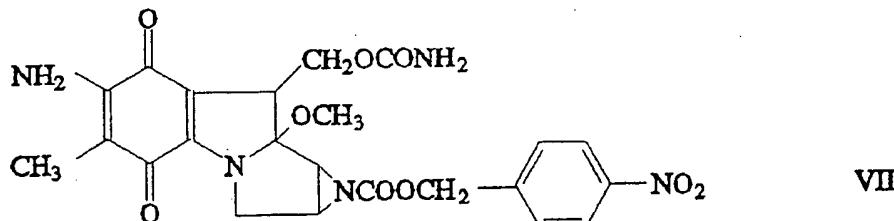
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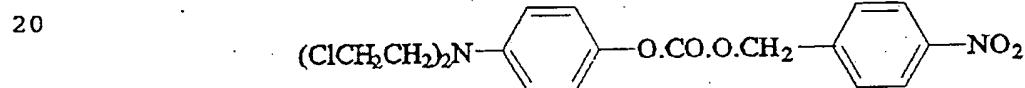
V

- 8 -



10 Similar p-nitrobenzyloxy derivatives can be made at the amino substituent of other actinomycins and of the other cytotoxic compounds of the type mentioned above.

15 In addition to forming p-nitrobenzyloxycarbonyl derivatives at an amino group on a cytotoxic compound, similar derivatives can be made at a hydroxy group, particularly a phenolic hydroxy group of a cytotoxic compound. Here, attention is directed at the phenolic nitrogen mustard compounds, and the compound of formula VIII:



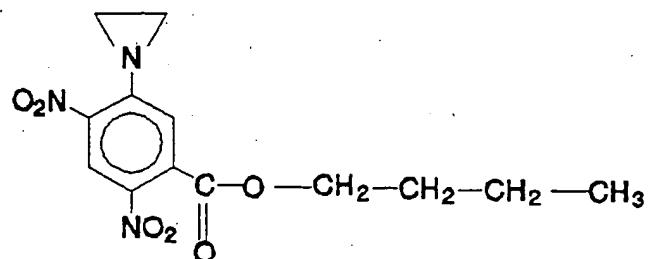
VIII

25 Suitable prodrugs also include other aromatic nitro compounds such as 5-chloro-2,4-dinitrobenzamide, 3,5-dinitrobenzamide, 3-nitrobenzamide, 4-nitrobenzamide and 5-nitro-2-furfuraldehydesemicarbazone (nitrofuranzone).

30 Particularly preferred prodrugs are CB 1954 (5-(aziridin-1-yl)-2,4-dinitrobenzamide), SN 23862 (5-(bis(2'-chloroethyl)amino)-2,4-dinitrobenzamide) and analogues of CB 1954 or SN 23862, such as those described in WO 93/11099 or, for example descarboxamido CB 1954 (1-aziridin-1-yl-2,4-dinitrobenzamide - known as CB 1837), N,N-dimethyl CB 1954 (N,N-dimethyl-(5-aziridin-1-yl)-2,4-dinitrobenzamide - known as CB 10-107), CB 10-199, CB 10-200, CB 10-201, CB 10-217, CB 10-021 and CB 10-214.

- 9 -

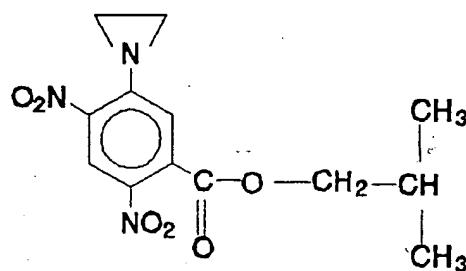
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CB 10-199

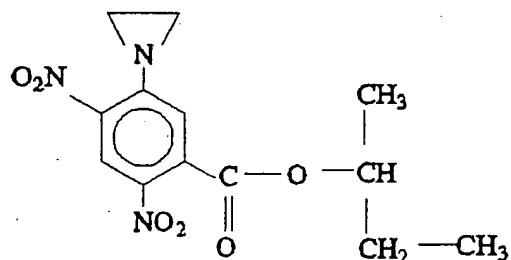
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CB 10-200

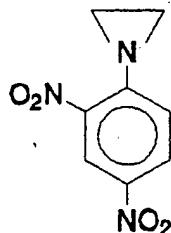
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CB 10-201

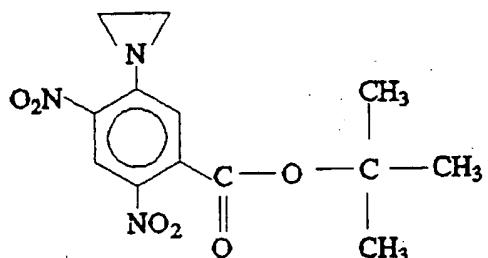
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CB 1837

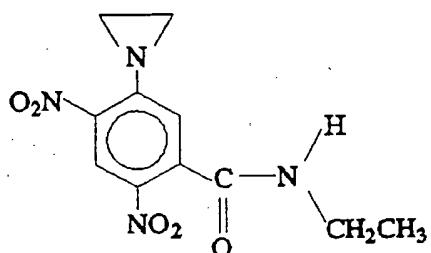
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- 10 -



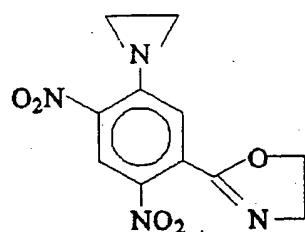
CB 10-217

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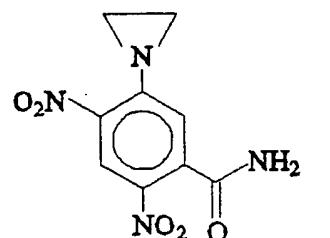
CB 10-021

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CB 10-214

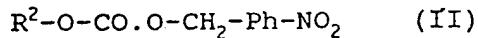
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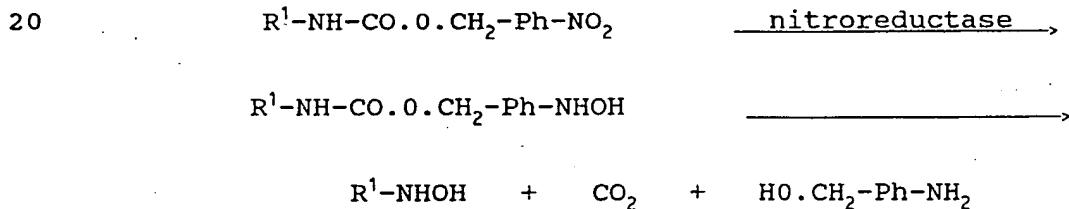
CB 1954

- 13 -

is a cytotoxic compound; and (II)



5 where Ph is as defined above and  $R^2$  is a group such that  $R^2-OH$  is a cytotoxic compound may be used as prodrugs in a VDEPT system in conjunction with a nitroreductase defined herein, including the E.coli nitroreductase described in WO93/08288. While the present invention is not dependent, for its definition, upon the exact mode of action of the nitroreductase on the prodrug, for 10 compounds of formula I or II, it is believed that the nitro group of the p-nitrophenyl-benzylcarbonyl residue is converted to the corresponding hydroxylamino group and that the resulting p-hydroxyl-aminobenzylcarbonyl compound automatically degrades 15 under the reaction conditions used for the enzymatic reduction to release the cytotoxic compound and form p-hydroxylaminobenzyl alcohol and carbon dioxide as by products in accordance with the following reaction scheme:



25 (Mauger et al J. Med. Chem. 1994 vol 37. p3452-3458).

For use in VDEPT, all types of prodrug should preferably be able 30 to enter cells. Accordingly, modifications may be made in the prodrug, eg to make the prodrug more or less lipophilic.

In order to bring about the reduction of the prodrug with the nitroreductase described herein, it is necessary to have a cofactor present in the reaction system. Nitroreductase requires 35 NAD(P)H as cofactor. Since NAD(P)H has a very short serum half-life, concentrations in the blood stream are very low. Accordingly, any nitroreductase produced according to the system

- 14 -

of the invention which is released into the blood stream by cell lysis will be unable to activate any circulating prodrug owing to the absence of NAD(P)H. Thus the presence or absence of cofactor allows a greater selectivity of the VDEPT system so that 5 prodrug is activated only within cells.

In VDEPT the prodrug will usually be administered following administration of the modified virus encoding a nitroreductase. Typically, the virus will be administered to the patient and then 10 the uptake of the virus by infected cells monitored, for example by recovery and analysis of a biopsy sample of targeted tissue.

The exact dosage regime for VDEPT will, of course, need to be determined by individual clinicians for individual patients and 15 this, in turn, will be controlled by the exact nature of the prodrug and the cytotoxic agent to be released from the prodrug but some general guidance can be given. Chemotherapy of this type will normally involve parenteral administration of both the prodrug and modified virus and administration by the intravenous 20 route is frequently found to be the most practical.

The vector of the system of the invention may be administered to animals or humans by any route appropriate to the condition to be treated, suitable routes including oral, rectal, nasal, 25 topical (including buccal and sublingual), vaginal and parenteral (including subcutaneous, intramuscular, intravenous, intradermal, intrathecal and epidural). It will be appreciated that the preferred route may vary with, for example, the condition of the recipient.

30 For each of the above-indicated utilities and indications the amount required of the individual active ingredients will depend upon a number of factors including the severity of the condition to be treated and the identity of the recipient and will 35 ultimately be at the discretion of the attendant physician. In general, however, for each of these utilities and indications, a suitable, effective dose will be in the range 1 µg to 10 g per

- 15 -

kilogram body weight of recipient per day, preferably in the range 0.01 to 100 mg per kilogram body weight per day and most preferably in the range 0.1 to 10 mg per kilogram body weight per day. The dose may, if desired, be presented as two, three, four or more sub-doses administered at appropriate intervals throughout the day. These sub-doses may be administered in unit dosage forms, for example, containing 1  $\mu$ g to 1000 mg, preferably 0.01 to 100 mg and most preferably 0.1 to 10 mg of active ingredient per unit dosage form.

10

While it is possible for the compounds to be administered alone it is preferable to present them as pharmaceutical formulations. The formulations of the present invention comprise at least one active ingredient, as above defined, together with one or more acceptable carriers thereof and optionally other therapeutic ingredients. The carrier(s) must be "acceptable" in the sense of being compatible with the other ingredients of the formulation and not deleterious to the recipients thereof.

20

The formulations include those suitable for oral, rectal, nasal, topical (including buccal and sublingual), vaginal or parenteral (including subcutaneous, intramuscular, intravenous, intradermal, intrathecal and epidural) administration. The formulations may conveniently be presented in unit dosage form and may be prepared by any of the methods well known in the art of pharmacy. Such methods include the step of bringing into association the active ingredient with the carrier which constitutes one or more accessory ingredients. In general the formulations are prepared by uniformly and intimately bringing into association the active ingredient with liquid carriers or finely divided solid carriers or both, and then, if necessary, shaping the product.

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Formulations of the present invention suitable for oral administration may be presented as discrete units such as capsules, cachets or tablets each containing a predetermined amount of the active ingredient; as a powder or granules; as a solution or a suspension in an aqueous liquid or a non-aqueous

- 16 -

liquid; or as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion. The active ingredient may also be presented as a bolus, electuary or paste.

5 A tablet may be made by compression or moulding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a suitable machine the active ingredient in a free-flowing form such as a powder or granules, optionally mixed with a binder (e.g. povidone, gelatin, hydroxypropylmethyl cellulose), lubricant, inert diluent, preservative, disintergrant (e.g. sodium starch glycolate, cross-linked povidone, cross-linked sodium carboxymethyl cellulose), surface-active or dispersing agent. Moulded tablets may be made by moulding in a suitable machine a mixture of the powdered compound moistened with an inert liquid diluent. The tablets may 10 optionally be coated or scored and may be formulated so as to provide slow or controlled release of the active ingredient therein using, for example, hydroxpropylmethylcellulose in varying proportions to provide desired release profile.

15

20 The formulations may be applied as a topical ointment or cream containing the active ingredient in an amount of, for example, 0.075 to 20% w/w, preferably 0.2 to 15% w/w and most preferably 0.5 to 10% w/w. When formulated in an ointment, the active ingredients may be employed with either a paraffinic or a water-miscible ointment base. Alternatively, the active ingredients 25 may be formulated in a cream with an oil-in-water cream base.

30 Formulations suitable for topical administration to the eye also include eye drops wherein the active ingredient is dissolved or suspended in a suitable carrier, especially an aqueous solvent for the active ingredient. The active ingredient is preferably present in such formulations in a concentration of 0.5 to 20%, advantageously 0.5 to 10% particularly about 1.5% w/w.

35 Formulations suitable for topical administration in the mouth include lozenges comprising the active ingredient in a flavoured

- 17 -

basis, usually sucrose and acacia or tragacanth; pastilles comprising the active ingredient in an inert basis such as gelatin and glycerin, or sucrose and acacia; and mouth-washes comprising the active ingredient in a suitable liquid carrier.

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Formulations for rectal administration may be presented as a suppository with a suitable base comprising for example cocoa butter or a salicylate.

10 Formulations suitable for nasal administration wherein the carrier is a solid include a coarse powder having a particle size for example in the range 20 to 500 microns which is administered in the manner in which snuff is taken, i.e. by rapid inhalation through the nasal passage from a container of the powder held close up to the nose. Suitable formulations wherein the carrier is a liquid, for administration as for example a nasal spray or as nasal drops, include aqueous or oily solutions of the active ingredient.

15 20 Formulations suitable for vaginal administration may be presented as pessaries, tampons, creams, gels, pastes, foams or spray formulations containing in addition to the active ingredient such carriers as are known in the art to be appropriate.

25 30 35 Formulations suitable for parenteral administration include aqueous and non-aqueous sterile injection solutions which may contain anti-oxidants, buffers, bacteriostats and solutes which render the formulation isotonic with the blood of the intended recipient; and aqueous-and non-aqueous sterile suspensions which may include suspending agents and thickening agents, and liposomes or other microparticulate systems which are designed to target the compound to blood components or one or more organs. The formulations may be presented in unit-dose or multi-dose containers, for example sealed ampoules and vials, and may be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid carrier, for example water for injections, immediately prior to use. Injection solutions and

- 18 -

suspensions may be prepared extemporaneously from sterile powders, granules and tablets of the kind previously described.

Preferred unit dosage formulations are those containing a daily dose or unit, daily sub-dose, as herein above recited, or an appropriate fraction thereof, of an active ingredient.

It should be understood that in addition to the ingredients particularly mentioned above the formulations of this invention may include other agents conventional in the art having regard to the type of formulation in question, for example those suitable for oral administration may include flavouring agents.

The prodrug of the system of the invention may also be administered to an animal or human by any of the means stated herein, in any of the formulations stated herein and in the dosage rates stated herein.

Examples of tumours that can be treated by the system of the invention are, for instance, sarcomas, including osteogenic and soft tissue sarcomas, carcinomas, e.g., breast-, lung-, bladder-, thyroid-, prostate-, colon-, rectum-, pancreas-, stomach-, liver-, uterine-, and ovarian carcinoma, lymphomas, including Hodgkin and non-Hodgkin lymphomas, neuroblastoma, melanoma, myeloma, Wilms tumor, and leukemias, including acute lymphoblastic leukaemia and acute myeloblastic leukaemia, gliomas and retinoblastomas.

According to a further embodiment of the invention, the viral vector is incorporated into a cell, such as, for example, a fibroblast, prior to administration to a patient. The gene may be introduced into the cell using standard techniques, such as, for example, calcium phosphate or electroporation. In this case targeting is achieved by the restriction of viral insertion to those cells synthesising DNA. It is also envisaged that targeting could be achieved by using antibodies to specific tumours. Unlike Antibody Directed Enzyme Prodrug Therapy the

- 19 -

antibody would be internalised. However the nature of virosomes are such that they are then targeted towards the cell nucleus and circumvent the compartmentalisation and breakdown normally associated with insertion.

5

The system of the present invention may be used to ablate normal tissue, for example breast tissue, particularly in women who are shown to have the "breast-cancer gene", or to ablate specific normal cells in animals for studies on normal tissue development 10 (pharmacogenics).

The prodrugs of the system of the invention, which are converted to active form by nitroreductase, are cytotoxic to non-cycling cells as well as to cycling cells.

15

The present invention is illustrated by means of the following Examples.

**Example 1.**

20 The effect of CB 1954 on the survival of V79 cells in the presence of the E. coli nitroreductase is shown in Table I. All treatments were for 2 hours at 37°C and the cells were then plated out for their resulting colony forming ability. NADH was used as a co-factor for both enzymes.

25

Table I

	<u>TREATMENT</u>	<u>% SURVIVAL</u>	<u>% DRUG REDUCTION</u>
30	CONTROL	100	-
	+ 500µM NADH	100	-
	+ 50µM CB 1954	100	<1.0
	+ NADH + CB 1954	41	<1.0
	+ Nitroreductase (2µg/ml)	94	-
35	+ NR + 50µM CB 1954	99	<1.0
	+ NR + 50µM CB 1954 + 500µM NADH	0.024	72

- 20 -

**Example 2.**

The effect of SN23862 on the survival of V79 cells in the presence of the E. coli nitroreductase. All treatments were for 2 hours at 37°C and the cells were then plated out for their resulting colony forming ability. The nitroreductase concentration was 2 $\mu$ g/ml and NADH was used as a co-factor. The initial cell density was 2 $\times$ 10<sup>5</sup>/mL.

10

**Table II**

	<u>TREATMENT</u>	<u>% SURVIVAL</u>	<u>% DRUG REDUCTION</u>
	CONTROL	100	-
15	+ 500 $\mu$ M NADH	100	-
	+ 50 $\mu$ M SN23862	100	<1.0
	+ NADH + SN23862	100	<1.0
	+ Nitroreductase (2 $\mu$ g/mL)	94	-
	+ NR + 50 $\mu$ M drug	99	<1.0
20	+ NR + SN23862 + 500 $\mu$ M NADH	0.007	95

**Example 3**

25 Generation of cytotoxicity by the action of NR upon the N-4-nitrobenzyloxycarbonyl derivative of actinomycin D (AMD).

30 Various concentrations of the prodrug were incubated with 1 mL of V79 cells (2 $\times$ 10<sup>5</sup>/mL), NADH (500  $\mu$ L) and NR (2, 5 or 10  $\mu$ g/mL) in PBS. After 2 h at 37°C, the cells were harvested and assayed for colony forming ability. The results are shown in Figure 1, from which it can be seen that the cytotoxicity of the prodrug is greatly enhanced in the presence of NR and is dependent on the concentration of the enzyme.

- 21 -

**Example 4**

Cytotoxicity of CB 1954 towards nitroreductase transduced NIH3T3 cells

5

As suggested by the observation that the bulk infected, unselected cell population could be efficiently killed, a bystander effect was seen when 3T3-NTR14 cells were mixed with untransduced NIH3T3 cells. Figure 2 shows that 90% inhibition of  $^3$ H-thymidine incorporation (shown as 10% decays/minute) could be achieved with only 50% transduced cells.

**Example 5**

15 Comparison of the nitroreductase/CB 1954 and thymidine kinase/ganciclovir enzyme/prodrug systems

Cells must be in S-phase for cytotoxic GCV-triphosphate incorporation into DNA, whereas activated CB 1954, which acts as 20 a cross linking agent does require active cell division for cytotoxicity. Indeed, arrest of NTR-expressing NIH3T3 cells by serum deprivation does not affect their killing by CB 1954 (Fig.3a), whereas similar arrest of TK-expressing NIH3T3 cells prevents GCV killing (Fig.3b).

25

**Example 6**

In vitro Expression of Nitroreductase (NR) in Breast Epithelial Cells

30

a) **Cloning Nitroreductase**

Two primers were used to amplify the coding region from a plasmid supplied by the Public Health Laboratory Service (PHLS), and designated NTR1003.

35

The sense primer is:

5' CGCAAAAAGCTTCACATTGAGTCATTATGG3'

- 22 -

This was designed to add a HindIII site, knock out an upstream ATG, and improve the initiation site for translation in mammalian cells.

5 The antisense primer is:

5'CGGCAAGGGATCCTTACACTTCGGTTAACGGTGATG3'

This was designed to add a BamHI site. The coding region was amplified using Pfu polymerase, and the HindIII-BamHI fragment was directionally cloned into pREP8 (Invitrogen). A clone with 10 the correct restriction map was sequenced from the RSV enhancer region to confirm that the 5' end of the clone was correct and was designed NRR8/3. pREP8 and pNRR8/3 were transfected into E.coli NFR-343 (lacking nitroreductase), and ampicillin resistant colonies were selected for assay. pREP8 and pR8NR were purified 15 for mammalian cell transfections using "Qiagen" reagents.

b) Expression of Nitroreductase In Epithelial Cells

HB4a, an SV40 conditionally immortalised human breast (luminal) cell line was transfected with pREP8 and pNRR8/3 using calcium 20 phosphate precipitation, and stable transfectants selected under 1mM Histidinol. For each plasmid 50-60 drug resistant colonies were obtained which were then pooled and continuously maintained under selection.

25 The pooled populations of HB4a/REP8 and HB4a/NR were expanded and examined for nitroreductase protein expression. Immunoblotting of whole cell lysates using a rabbit polyclonal antibody, rb 6s4/ntr, showed HB4a/NR to express large amounts of nitroreductase protein which bands at the appropriate weight as 30 compared to recombinant E.coli nitroreductase protein (Figure 4). As expected HB4a/REP8 did not express any nitroreductase protein.

c) Enzymatic Reduction of CB 1954

CB 1954 (100 $\mu$ M) and NADH (500 $\mu$ M) were incubated with a cell 35 lysate prepared by sonication (250 $\mu$ l, 1 mg/mL protein) in 10mM sodium phosphate buffer (pH7) at 37°C. At various times aliquots (10 $\mu$ l) were injected onto a Partisphere SCX (110 x 4.7mm) HPLC

- 23 -

column and eluted isocratically (2ml/min) with 50mM NaH<sub>2</sub>PO<sub>4</sub> in 1% (v/v) methanol. The eluate was continuously monitored for absorption at 260, 310, 340nm using a diode-array detector. Alternatively, [U-<sup>3</sup>H]CB 1954 was added to give an activity of 1.6 x 10<sup>5</sup> dpm per nmole). Samples (0.3ml) were collected and their tritium activity determined by liquid scintillation counting. Protein concentration was determined by a standard method (Biorad), calibrated against bovine albumin.

10 d) **Determination of cell survival**

Cells were trypsinised and resuspended in fresh media at 2 x 10<sup>5</sup> cells per mL. They were then treated for two hours with CB 1954 (10  $\mu$ l of appropriate stock in DMSO). The treated cells were then spun down, washed with fresh media, and plated out in triplicate at various concentrations. Cells were fixed and stained after 14 days incubation at 37°C in a humidified atmosphere of 5% CO<sub>2</sub> and 95% air.

15 e) **Expression in HOSPIP cells**

20 The modified gene described above was ligated into the vectors pREP4 and pREP8. These two vectors with high level constitutive transcription from the RSV LTR have Hygromycin and Histidinol selectable markers respectively for coexpression of recombinant proteins. Both of these constructs have been transfected into 25 the rat mammary carcinoma cell line HOSPIP by the calcium phosphate technique and are currently under appropriate selection conditions to isolate resistant clones.

30 f) **Determination of DNA interstrand crosslinks**

HB4a/NR cells were radiolabelled by growth for 48 hours in [<sup>3</sup>H]-thymidine. The cells were then treated with either 0, 10 or 50  $\mu$ M CB 1954 for 24 hours and their DNA then analysed by sedimentation in alkaline sucrose.

Results**Enzymatic Reduction of CB 1954**

HB4a/NR cells but not HBa/REP8 cells showed a time dependent decrease in the concentration of CB 1954 (Fig 5). Examination of the traces also indicated the formation of the 2- and 4-hydroxylamino reduction products of CB 1954. This was confirmed by the use of radiolabelled prodrug (Fig. 6). The protein concentration of the HB4a/NR lysate in the assay mixture was determined to be 0.3 mg/mL and the enzyme activity estimated to be 0.05  $\mu$ g/mL by comparison with the pure protein (see Figs. 5 and 6). Thus NR activity is 1.7  $\mu$ g/mg cell protein (~1.7  $\mu$ g/10<sup>6</sup> cells).

**Cell Survival**

The plating efficiency of both the HB4a/NR and HB4a/REP8 cell lines was poor and cells only grew when plated at a high initial cell density ( $1 \times 10^4$  per dish). These plates were scored by eye for cell growth. Results are shown in Table III. There is a dramatic difference in cell survival between the two cell lines. After a 2 hour exposure the HB4a/NR line exhibits cytotoxicity at 1.0  $\mu$ M while the HB4a/REP8 line shows no cytotoxicity until the dose is >100  $\mu$ M.

**DNA Crosslinked Formation**

Confirmation that the cytotoxicity of CB 1954 in HB4a/NR cells is due to its enzymic reduction is obtained by demonstrating the ability of this compound to form DNA interstrand crosslinks (Fig. 7). Increasing amounts of CB 1954 produce a progressive increase in the amount of DNA that is crosslinked as indicated by the increasing proportion of DNA of higher molecular weight which sediments further into the alkaline sucrose gradient (sedimentation is from left to right) (Fig. 7). DNA strand breakage (either frank breaks or alkali labile sites) is also observed and for clarity the sedimentation profiles are shown relative to a modelled control of the same molecular weight as the strand-broken experimental DNA. 10  $\mu$ M CB 1954 produces about

- 25 -

6 crosslinks and 25 breaks per  $10^9$  daltons of DNA whilst  $50\mu\text{M}$  CB 1954 produces 12 crosslinks and 28 breaks. These effects are not seen in untreated cells.

5

TABLE III

The effect of CB 1954 on the survival of human HB4a/NR or HB4a/REP8 cell lines. All treatments were for 2 hours at  $37^\circ\text{C}$ .

10

[CB 1954] $\mu\text{M}$	4A/Rep	4A/NR
0.0	+++	+++
1.0	+++	+--
10	+++	---
100	+++	---
1000	---	---

15

- 26 -

SEQUENCE LISTING

(1) GENERAL INFORMATION:

(i) APPLICANT:

- (A) NAME: Cancer Research Campaign Technology Limited
- (B) STREET: Cambridge House
- (C) CITY: 6-10 Cambridge Terrace
- (D) STATE: Regent's Park
- (E) COUNTRY: LONDON
- (F) POSTAL CODE (ZIP): NW1 4JL

(ii) TITLE OF INVENTION: Improvements Relating to Cancer  
Therapy

(iii) NUMBER OF SEQUENCES: 2

(iv) COMPUTER READABLE FORM:

Not Applicable

(v) CURRENT APPLICATION DATA:

Not Applicable

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1167 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: double
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(vi) ORIGINAL SOURCE:

- (A) ORGANISM: Escherichia coli
- (B) STRAIN: B

(ix) FEATURE:

(A) NAME/KEY: CDS  
 (B) LOCATION: 176..829

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

TCGGATCTG ATCAACGATT CGTGGAAATCT GGIGGGTGTAT GGTCTGGCTA AACGCGATCA	60		
AAAAAGAGTG CGTCCAGGCT AAAGCGGAAA TCTATAGCGC ATTTTCTCG CTTACCAATT	120		
CTGGTGAAC CTTGAACTCT GCTGGCACCGC AAAATTACIT TCACATGGAG TCTTT ATG	178		
Met			
1			
GAT ATC ATT TCT GTC GCC TTA AAG CGT CAT TCC ACT AAG GCA TTT GAT	226		
Asp Ile Ile Ser Val Ala Leu Lys Arg His Ser Thr Lys Ala Phe Asp			
5	10	15	
GCC AGC AAA AAA CTT ACC CCG GAA CAG GCG GAG CAG ATC AAA ACG CTA	274		
Ala Ser Lys Lys Leu Thr Pro Glu Gln Ala Glu Gln Ile Lys Thr Leu			
20	25	30	
CTG CAA TAC AGC CCA TCC AGC ACC AAC TCC CAG CCG TGG CAT TTT ATT	322		
Leu Gln Tyr Ser Pro Ser Ser Thr Asn Ser Gln Pro Trp His Phe Ile			
35	40	45	
GTT GCC AGC ACG GAA GAA GGT AAA GCG CGT GTT GCC AAA TCC GCT GCC	370		
Val Ala Ser Thr Glu Glu Gly Lys Ala Arg Val Ala Lys Ser Ala Ala			
50	55	60	65
GGT AAT TAC GTG TTC AAC GAG CGT AAA ATG CTT GAT GCC TCG CAC GTC	418		
Gly Asn Tyr Val Phe Asn Glu Arg Lys Met Leu Asp Ala Ser His Val			
70	75	80	
GTG GTG TTC TGT GCA AAA ACC GCG ATG GAC GAT GTC TGG CTG AAG CTG	466		
Val Val Phe Cys Ala Lys Thr Ala Met Asp Asp Val Trp Leu Lys Leu			
85	90	95	

- 28 -

GTG GGT GAC CAG GAA GAT GCC GAT GGC CGC TTT GCC ACG CGG GAA GCG	514
Val Val Asp Gln Glu Asp Ala Asp Gly Arg Phe Ala Thr Pro Glu Ala	
100 . . . . . 105 . . . . . 110	
AAA GCC GCG AAC GAT AAA GGT CGC AAG TTC TTC GCT GAT ATG CAC CGT	562
Lys Ala Ala Asn Asp Lys Gly Arg Lys Phe Phe Ala Asp Met His Arg	
115 . . . . . 120 . . . . . 125	
AAA GAT CTG CAT GAT GCA GAG TGG ATG GCA AAA CAG GTT TAT CTC	610
Lys Asp Leu His Asp Asp Ala Glu Trp Met Ala Lys Gln Val Tyr Leu	
130 . . . . . 135 . . . . . 140 . . . . . 145	
AAC GTC GGT AAC TTC CTG CTC CGC GTG GCG GCT CTG GGT CTG GAC GCG	658
Asn Val Gly Asn Phe Leu Leu Gly Val Ala Ala Leu Gly Leu Asp Ala	
150 . . . . . 155 . . . . . 160	
GTA CCC ATC GAA GGT TTT GAC GCC GCC ATC CTC GAT GCA GAA TTT GGT	706
Val Pro Ile Glu Gly Phe Asp Ala Ala Ile Leu Asp Ala Glu Phe Gly	
165 . . . . . 170 . . . . . 175	
CTG AAA GAG AAA GGC TAC ACC AGT CTG GTG GTT CGG GTC GGT CAT	754
Leu Lys Glu Lys Gly Tyr Thr Ser Leu Val Val Val Pro Val Gly His	
180 . . . . . 185 . . . . . 190	
CAC AGC GTT GAA GAT TTT AAC GCT ACG CTG CGG AAA TCT CGT CTG CGG	802
His Ser Val Glu Asp Phe Asn Ala Thr Leu Pro Lys Ser Arg Leu Pro	
195 . . . . . 200 . . . . . 205	
CAA AAC ATC ACC TTA ACC GAA GTG TAATTCTCTC TGGCGGGCA TCTGCCGGC	856
Gln Asn Ile Thr Leu Thr Glu Val	
210 . . . . . 215	
TATTTCCCTCT CAGATTCTCC TGATTTGCAT AACCCCTGTT CAGCCGTCAT CATAGGCTGC	916
TGTTGTATAA AGGAGACGTT ATGCAGGATT TAATATCCCA GGTGAAGAT TTAGGGGTA	976
TTGAGATCGA TCACACCACC TOGATGGTGA TGATTTCCG TATTATTTT CTGACCGCG	1036

- 29 -

TOGTCGGTGCA TATTATTTG CATTGGGTGG TACTGOGGAC CTTCGAAAAA CGTGCCATCG 1096  
CCAGITTCACG GCCTTGGGTG CAAATCATTAA CCCAGAATAA ACTCTTCCAC CGTTTAGCTT 1156  
TTACCCCTGCA G 1167

## (2) INFORMATION FOR SEQ ID NO:2:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 217 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Asp Ile Ile Ser Val Ala Leu Lys Arg His Ser Thr Lys Ala Phe  
1 5 10 15

Asp Ala Ser Lys Lys Leu Thr Pro Glu Gln Ala Glu Gln Ile Lys Thr  
20 25 30

Leu Leu Gln Tyr Ser Pro Ser Ser Thr Asn Ser Gln Pro Trp His Phe  
35 40 45

Ile Val Ala Ser Thr Glu Glu Gly Lys Ala Arg Val Ala Lys Ser Ala  
50 55 60

Ala Gly Asn Tyr Val Phe Asn Glu Arg Lys Met Leu Asp Ala Ser His  
65 70 75 80

Val Val Val Phe Cys Ala Lys Thr Ala Met Asp Asp Val Trp Leu Lys  
85 90 95

Leu Val Val Asp Gln Glu Asp Ala Asp Gly Arg Phe Ala Thr Pro Glu  
100 105 110

- 30 -

Ala Lys Ala Ala Asn Asp Lys Gly Arg Lys Phe Phe Ala Asp Met His  
115 120 125

Arg Lys Asp Leu His Asp Asp Ala Glu Trp Met Ala Lys Gln Val Tyr  
130 135 140

Leu Asn Val Gly Asn Phe Leu Leu Gly Val Ala Ala Leu Gly Leu Asp  
145 150 155 160

Ala Val Pro Ile Glu Gly Phe Asp Ala Ala Ile Leu Asp Ala Glu Phe  
165 170 175

Gly Leu Lys Glu Lys Gly Tyr Thr Ser Leu Val Val Val Pro Val Gly  
180 185 190

His His Ser Val Glu Asp Phe Asn Ala Thr Leu Pro Lys Ser Arg Leu  
195 200 205

Pro Gln Asn Ile Thr Leu Thr Glu Val  
210 215

CLAIMS

1. A system comprising:
  - 5 (i) a viral vector comprising a nucleotide sequence encoding a nitroreductase, which nitroreductase is capable of converting a prodrug into a cytotoxic drug; and
  - (ii) a prodrug capable of being converted into a cytotoxic drug by the nitroreductase encoded by the vector.
- 10 2. A system according to claim 1 wherein the nucleotide sequence contains the oligonucleotide of SEQ ID No.1, fragment thereof or oligonucleotide hybridisable thereto.
- 15 3. A system according to claim 1 or 2 wherein the nitroreductase is of the sequence SEQ ID No.2, fragment thereof or homologue thereof.
4. A system according to any one of the preceding claims wherein the viral vector comprises a promoter operably linked to the sequence encoding the polypeptide.
- 20 5. A system according to any one of the preceding claims wherein the vector is in the form of a viral particle.
6. A system according to any one of claims 1 to 4 wherein the vector is incorporated into a cell.
7. A system according to any one of the preceding claims wherein the prodrug is a nitrogen mustard compound.
- 25 8. A system according to any one of the preceding claims wherein the prodrug is 1-aziridin-1-yl-2,4-dinitrobenzamide or 2,4-dinitro-5-(N,N-di-(2-chloroethyl))aminobenzamide.
9. A viral vector for use in a system as claimed in any one of the preceding claims.
- 30 10. A viral vector for use in a system as claimed in any one of claims 1 to 8 in a method of medical treatment.
11. Use of a viral vector as defined in any one of claims 1 to 6 for the manufacture of a medicament for the treatment of tumours.
- 35 12. A prodrug for use in a system as claimed in any one of claims 1 to 8.
13. A method of treating tumours which comprises administering to an affected individual an effective amount of a vector as defined in any one of the preceding claims and an

- 32 -

effective amount of a prodrug capable of being converted to a cytotoxic drug by the nitroreductase encoded by the vector.

14. A system according to any one of claims 1 to 8 for use in a method of treatment of the human or animal body.

5 15. A product containing a viral vector as defined in any one of claims 1 to 6 and a prodrug as defined in claim 1, 7 or 8 as combined preparation for simultaneous, separate or sequential use in the treatment of tumours.

10 16. A method of ablating tissue which comprises administering to a human or animal body an effective amount of a vector as defined in any one of the preceding claims and an effective amount of a prodrug capable of being converted to a cytotoxic drug by the nitroreductase encoded by the vector.

15 17. A product containing a viral vector as defined in any one of claims 1 to 6 and a prodrug as defined in claim 1, 7 or 8 as a combined preparation for simultaneous, separate or sequential use in the ablation of tissue.

1/5

Fig.1.

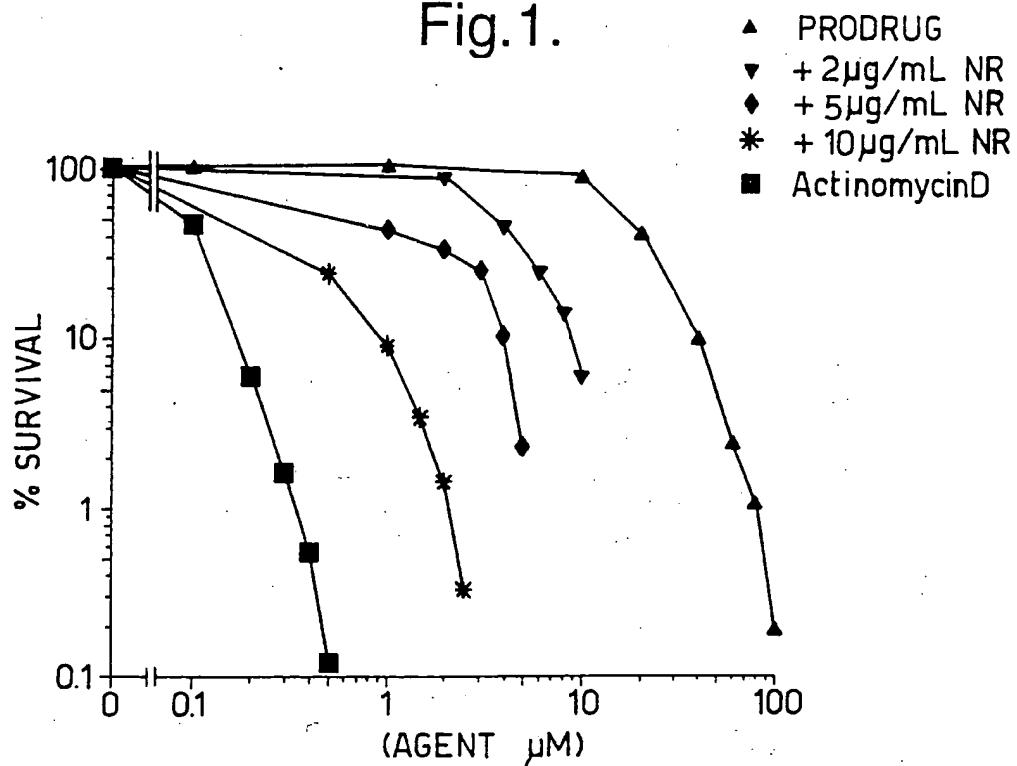


Fig.2.

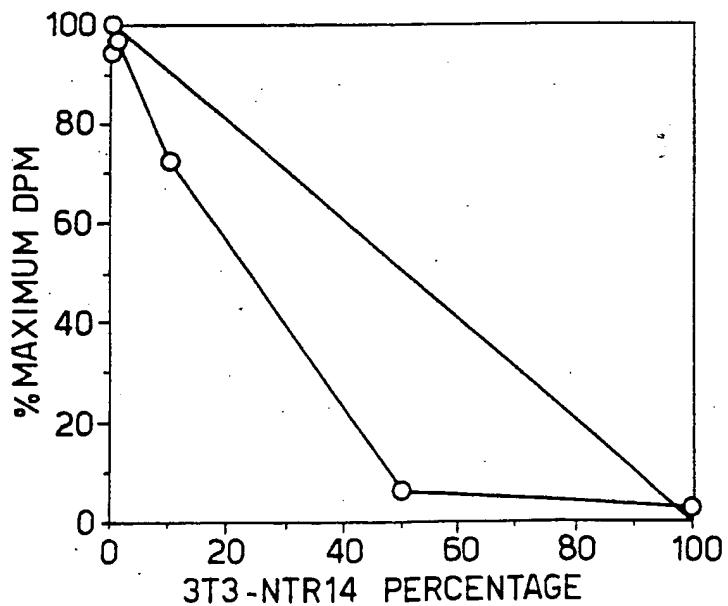


Fig.3A

2/5

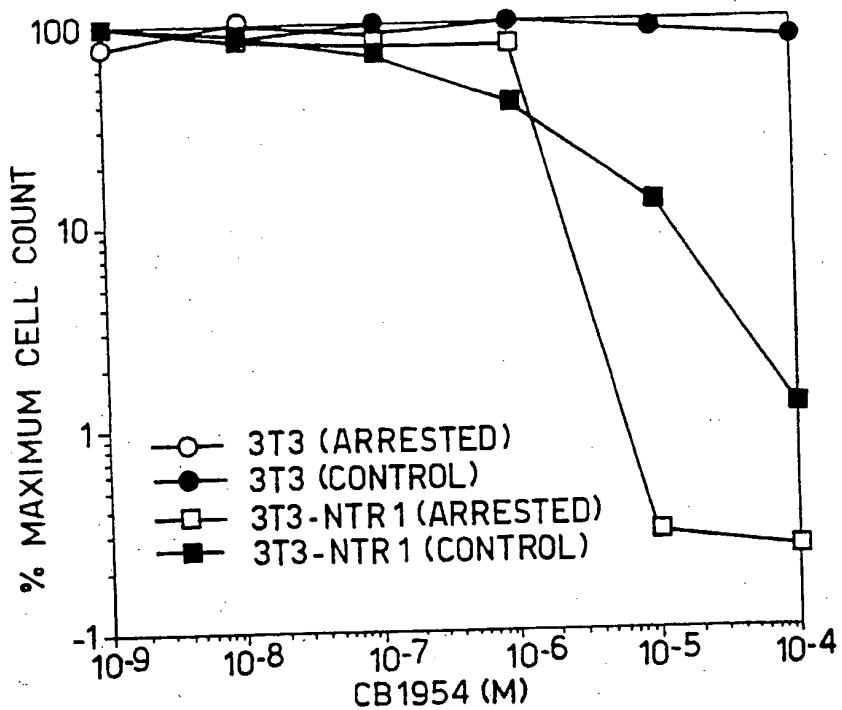
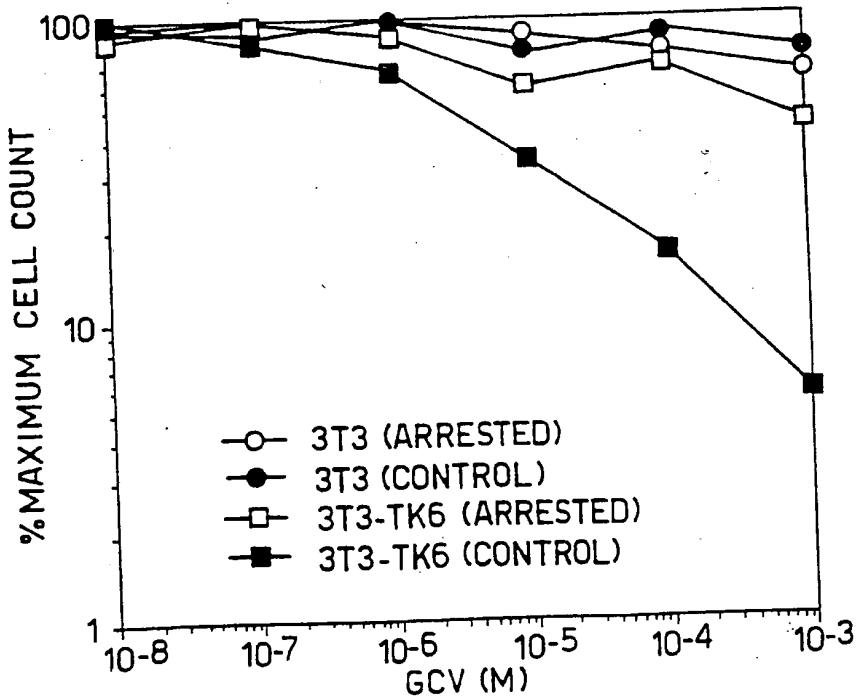


Fig.3B



3/5

Fig.4.

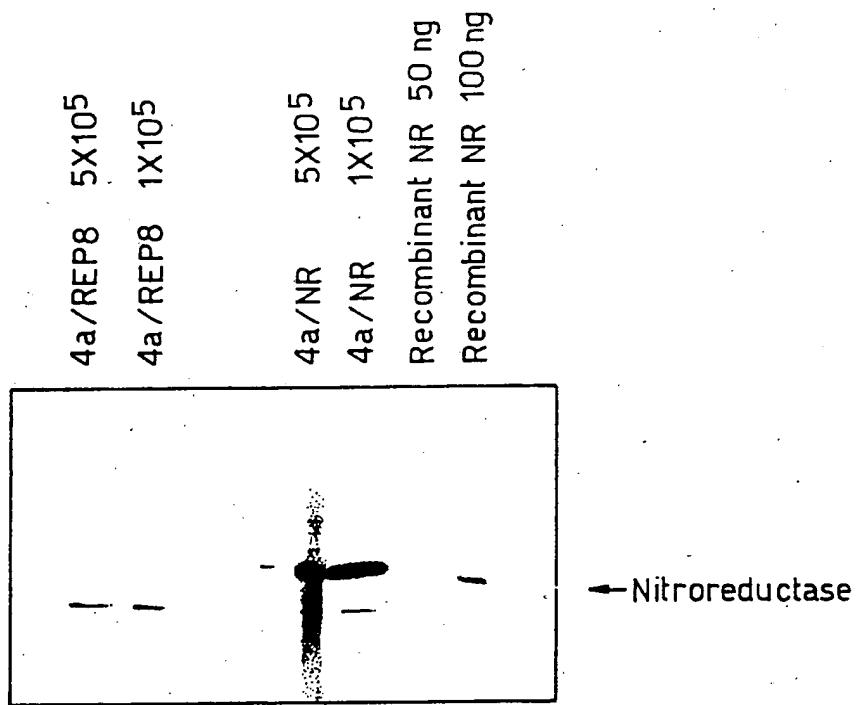


Fig.5.

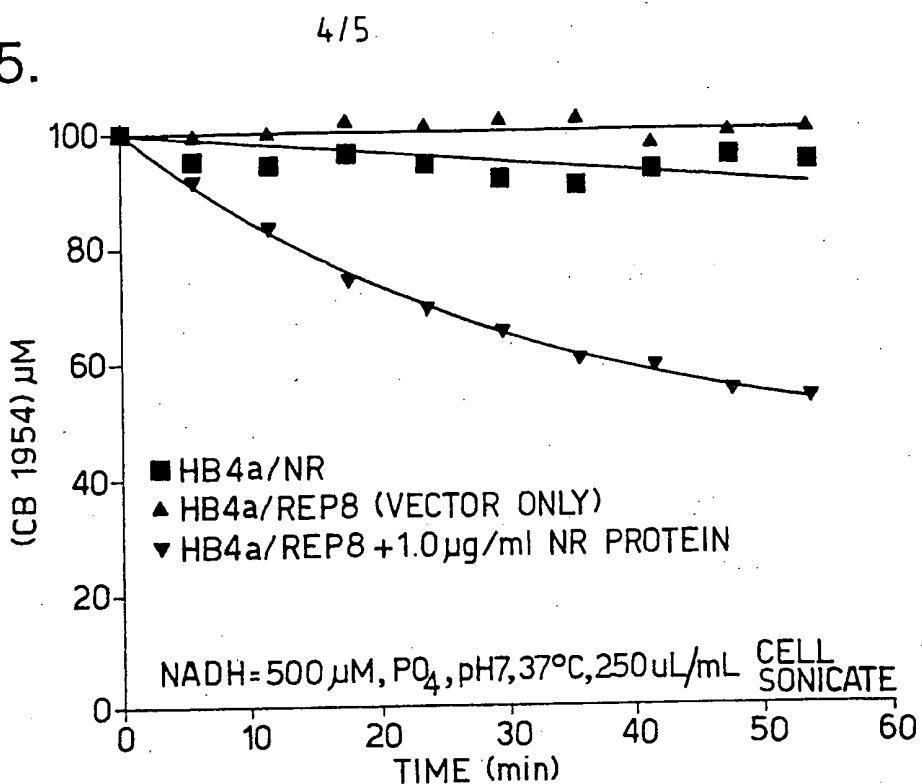
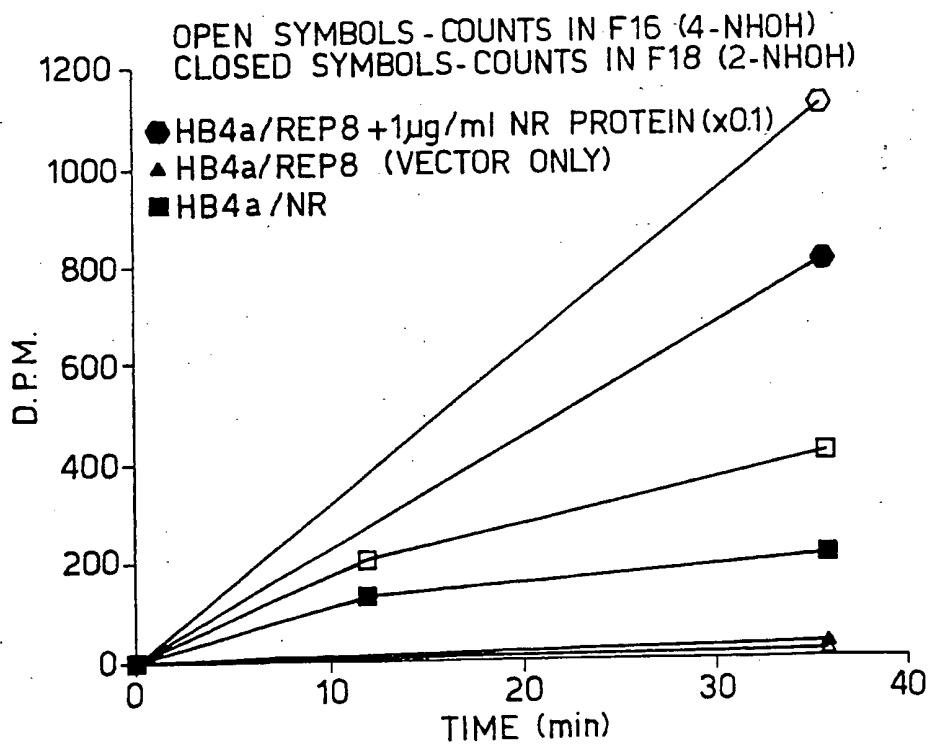
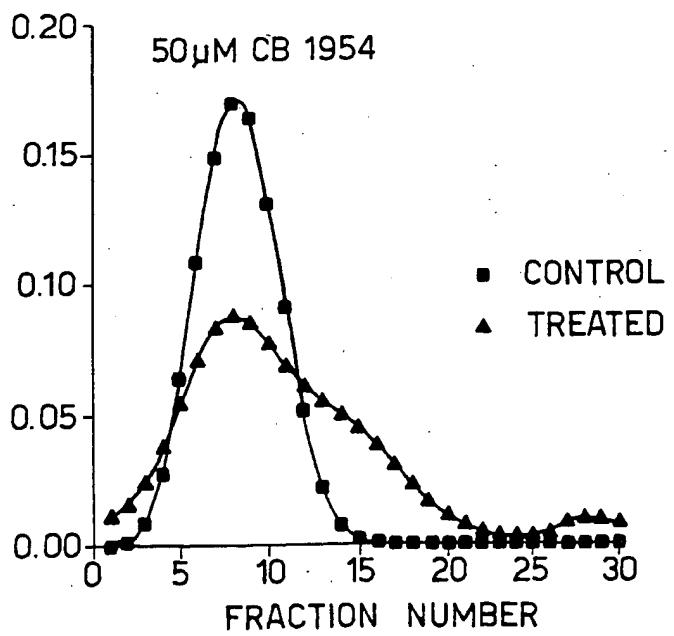
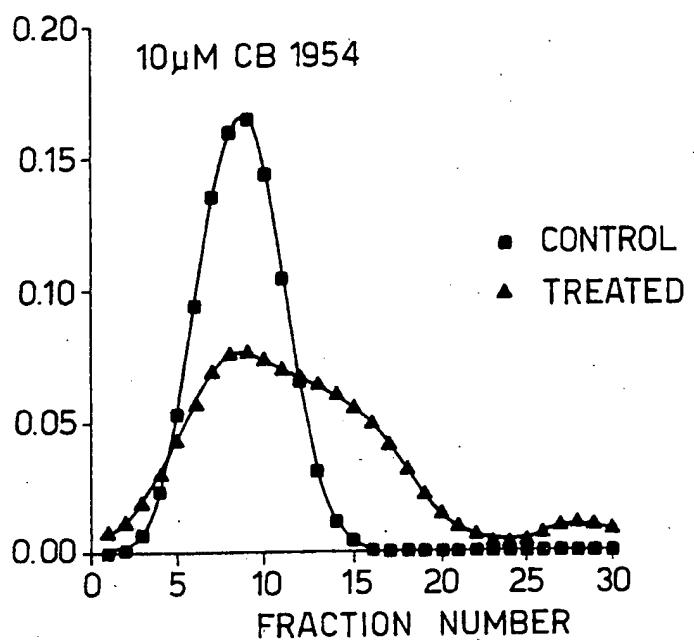


Fig.6.



5 / 5

Fig.7.



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